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Effect of Palm Oil Fuel Ash Fineness on Packing Effect and Pozzolanic Reaction of Blended Cement Paste

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Abstract

This paper presents the effect of particle size of palm oil ash on packing effect and pozzolanic reaction in cement paste. Ground palm oil fuel ash and ground river sand, having high crystalline and insoluble material of 2 different size with median particle size 15±1 and 2±1µm. Portland cement type I was replaced by palm oil fuel ash or ground river sand at 10, 20, 30 and 40 by weight of cementitious materials. The water to binder ratio (W/B) of 0.35 was used for all the blended cement paste mixes. Compressive strength of cement paste, percentage compressive strength due to hydration reaction, percentage compressive strength due to packing effect, percentage compressive strength due to pozzolanic reaction and fractured surface of cement paste were determined. The results showed that the packing effect of palm oil fuel ash cement paste increases with high fineness. Percentage pozzolanic reaction with median particle size smaller than cement was 12-23% at the age of 28 days. Palm oil fuel ash high fineness is good pozzolanic material and it can be used replace Portland cement Type I at the rate of 30% by weight of binder.

Keywords: palm oil fuel ash, packing effect, pozzolanic reaction, microstructure.

1. Introduction

Palm oil fuel ash (POA) is a by-product from small power plant which use palm fiber, shell and empty fruit bunches as a fuel and burnt at 800 - 1000 °C. In Thailand, more than 100,000 tons of palm oil fuel ash are produced annually (Tangchirapat et al. 2009a). The main chemical composition of palm oil fuel ash is silica. Many researchers have studied the use of palm oil fuel ash in concrete. (Sata et al. 2004) studied the

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utilization of palm oil fuel ash in high-strength concrete and the result showed that POA can use pozzolan to produce high strength concrete. In addition, the utilization of POFA can improve concrete strength and permeability (Chindaprasirt et al. 2007a). In addition, partial replacement of OPC with POA help sulfate resistance (Tangchirapat et al. 2007) and chloride resistance of concrete (Chindaprasirt et al. 2008).

Compressive strength of cement paste containing pozzolan materials is contributed by hydration reaction, packing effect and pozzolanic reaction. Hydration reaction is the chemical between Portland cement and water as pozzolanic reaction silica compound and calcium hydroxide.

But packing effect is a proper arrangement of small particles which fill the voids and contribute to the increment of compressive strength (Goldman and Bentur 1993; Isaia et al. 2003). However, researchers (Goldman and Bentur 1993; Tangpagasit et al. 2005) have to find the compressive strength due to packing effect and pozzolanic reaction use of insoluble material.

The objective of this research is to study the effect of palm oil fuel ash fineness on packing effect and pozzolanic reaction of blended cement paste hydration reaction, pozzolanic reaction and packing effect. This knowledge could be advantageous of using waste materials.

2. Experimental

2.1. Materials

Ordinary Portland cement (OPC) was used for all cement paste mixtures. Palm oil fuel ash was formed from a thermal plant from the south of Thailand. It was sieved through a no. 16 to separate large particles and unburnt palm fiber. Palm oil fuel ash (POA) and river sand (RS) were ground to two different sizes with a ball mill. The abbreviations G1 and G2 were used to identify ground POA and RS as sizes nearby cement and small sizes, respectively.

2.2. Mix proportion and curing

Ordinary Portland cement is partially replaced by POA and RS at the ratio of 0%, 10%, 20%, 30% and 40% by weight of binder. The water to binder ratio (W/B) was constantly 0.35 throughout the investigation. The cast specimens were covered with plastic to prevent water loss. Thereafter, they were cured in saturated lime water 23±2 ºC.

2.3. Compressive strength

The cube specimens of size 50 × 50 × 50 mm were used for the compressive strength test of the cement paste. They were tested at the age 7, 28, 60 and 90 days in according with ASTM C 109. Each compressive strength value was the average of five samples.

2.4. Scannig electron microscope

Paste cubes at the required ages of 7 and 28 days were broken from the center into small fragments. Hydration of the paste was stopped by freezing and drying. The fracture surface was observed by using SEM (JOEL JSM-6400). All samples were coated with gold before using SEM analysis.

3. Results and Discussion

3.1. Characteristics of OPC, POA and RS

Physical properties of the materials are shown in Table 1. The specific gravities of G1POA, G2POA, G1RS and G2RS were 2.36, 2.48, 2.59 and 2.61, respectively. Surface area by BET fineness of G1POA, G2POA, G1RS and G2RS were 2,340, 18,000, 3,880 and 6,307 cm^2/g, respectively. The effect of grinding on specific gravity and surface area increased. Similar finding was reported by investigations (Chindaprasirt et al. 2004; Rukzon et al. 2009). The median particle sizes of G1POA, G2POA, G1RS and G2RS were 15.6, 2.1, 15.9 and 2.2 respectively. Figure 1 shows a comparison of the particle size distributions of Portland cement type I, palm oil fuel ash and river sand. It can be divided into two groups as sizes nearby cement and small sizes. It should be distinguished that palm oil fuel ash and river sand have same particle size distribution.

The chemical compositions of OPC, POA and RS are given in Table 2. The main chemical composition of G1POA and G2POA was SiO_2. Total amount of SiO_2, Al_2O_3 and Fe_2O_3 of G1POA and G2POA were 56.9% and 58.6%, respectively. For insoluble material, the main chemical composition is SiO_2, which is approximately 93-94%.

Table 1: Physical properties of materials used

Sample	Specific gravity	Median particle size (µm)	Blaine fineness (cm^2/g)	BET surface area (cm^2/g)
OPC	3.14	14.6	3,600	-
G1POA	2.36	15.6	-	2,340
G2POA	2.48	2.1	-	18,000
G1RS	2.59	15.9	-	3,880
G2RS	2.61	2.2	-	6,307

Table 2: Chemical composition of materials used

Chemical composition (%)	OPC	G1POA	G2POA	G1RS	G2RS
Silicon dioxide (SiO_2)	20.8	54.0	55.7	92.0	91.2
Aluminum oxide (Al_2O_3)	4.7	0.9	0.9	1.6	1.8
Iron oxide (Fe_2O_3)	3.4	2.0	2.0	0.6	0.2
Calcium oxide (CaO)	65.3	12.9	12.5	0.9	0.7
Magnesium oxide (MgO)	-	4.9	5.1	0.1	0.1
Sodium oxide (Na_2O)	0.1	1.0	1.0	0.1	0.1
Potassium oxide (K_2O)	0.4	13.5	11.9	2.2	2.3
Sulfur trioxide (SO_3)	2.7	4.0	2.9	-	-
Loss on ignition (LOI)	0.9	3.7	4.7	2.1	1.8
$SiO_2 + Al_2O_3 + Fe_2O_3$	-	56.9	58.6	94.2	93.2

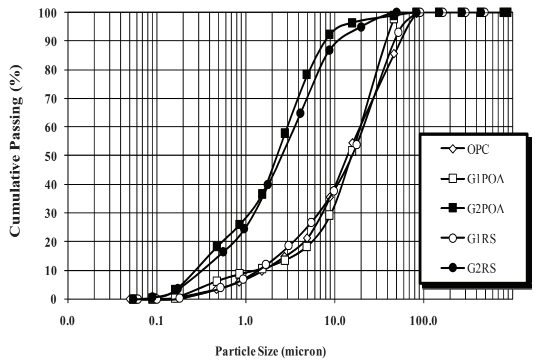


Figure 1: Particle size distribution of materials used

3.2. Compressive strength of cement paste

The compressive strength of POA blended cement pastes are shown in Table 3. It was found that at 28 days, the compressive strengths of 10G1POA, 20G1POA, 30G1POA and 40G1POA cement paste were 75, 72, 66.7, and 61.5 MPa, respectively, while that of the OPC was 75 MPa. At 90 days, compressive strengths of the 20G1POA and 30G1POA cement paste were 103% and 98% of OPC cement paste at the same age. The increase in compressive strength could be ascribed by the higher pozzolanic reaction of the POA. The compressive strengths of 10G2POA, 20G2POA, 30G2POA and 40G2POA cement paste were 80.2, 77.3, 72.8 and 66.5 MPa or 107%, 103%, 97% and 89 % of OPC cement paste, respectively, at 28 days. The fineness of G2POA had greater pozzolanic reaction and small particles could fill effect in the voids of the cement paste, consequently, compressive strength of the cement paste G2POA is used 10-30 % higher than that of the OPC cement paste at 90 days.

Table 3: Compressive strength of cement pastes

Symbol	Compressive strength (MPa-normalized)			
	7 days	28 days	60 days	90 days
OPC	53.0-100	75.0-100	84.6-100	99.1-100
10G1POA	50.3-95	75.0-100	86.3-102	102.0-103
20G1POA	48.3-91	72.0-96	84.6-100	102.0-103
30G1POA	44.5-84	66.7-89	78.6-93	97.1-98
40G1POA	41.0-77	61.5-82	72.8-86	88.1-89
10G2POA	55.3-104	80.2-107	93.0-110	109.0-111
20G2POA	51.9-98	77.3-103	92.2-109	109.6-111
30G2POA	48.3-91	72.8-97	86.3-102	104.0-105
40G2POA	44.0-83	66.5-89	78.6-93	94.1-95

3.3 Percentage compressive strength of cement paste due to hydration reaction

Compressive strength of ground river sand cement pastes are shown in Table 4. Compressive strength of ground river sand cement paste was lower than that of the G1POA and G2POA cement paste with the same replacement and same particle size. Percentage compressive strength due to hydration reaction is constant. For example, compressive strengths of 20G1RS cement paste at the ages of 7, 28, 60 and 90 days were 81%, 81%, 80% and 79% of the OPC cement paste, respectively. The percentage of compressive strength of cement paste containing POA was shown to increase, while the percentage of compressive strength of ground river sand cement paste did not show an increase. This is because ground river sand cannot be pozzolanic reaction $Ca(OH)_2$ and SiO_2.

Table 4 : Compressive strength of ground river sand cement pastes

Symbol	Compressive strength (MPa-normalized)				Average (%)
	7 days	28 days	60 days	90 days	
OPC	53.0-100	75.0-100	84.6-100	99.1-100	100
10G1RS	48.3-91	67.2-90	77.5-90	90.1-91	91
20G1RS	42.9-81	60.8-81	67.9-80	78.6-79	80
30G1RS	37.8-71	53.8-72	60.3-71	70.4-71	71
40G1RS	31.8-85	63.4-85	70.6-83	83.2-84	84
10G2RS	49.6-94	77.1-96	80.8-96	94.1-95	95
20G2RS	45.2-85	63.4-85	70.6-83	83.2-84	84
30G2RS	39.8-75	56.7-76	63.3-75	75.3-76	76
40G2RS	35.0-66	49.4-66	55.6-66	63.0-64	66

3.4 Percentage compressive strength of cement paste due to packing effect

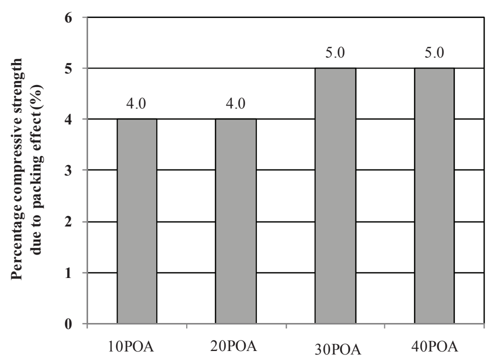


Figure 2: Percentage compressive strength of cement pastes due to packing effect

The packing effect is determined by difference in compressive strength of cement pastes containing different particle sizes of ground river sand cement paste. Percentage compressive strengths of cement pastes due to packing effect are shown in Figure 2. The percentage compressive strengths due to packing effect 10POA, 20POA, 30POA and 40POA cement paste were 4%, 4%, 5% and 5% of the OPC cement paste, respectively. From the results, the high fineness of the particles obtained on the compressive strength of cement paste.

3.5 Percentage compressive strength of cement paste due to pozzolanic reaction

Percentage compressive strength of cement pastes due to pozzolanic reaction are given in Table 5. The difference in compressive strength between palm oil fuel ash cement paste and ground river sand cement paste, at same particle size, same replacement, and same age is due to pozzolanic reaction. Percentage compressive strengths due to pozzolanic reaction of 10G1POA cement paste at the ages of 7, 28, 60 and 90 days were 4%, 9%, 11% and 12%, respectively, while at 28 days the compressive strength was higher than that of the control cement paste OPC. This is because of pozzolanic reaction (Tangchirapat et al. 2009b). For cement paste 40G1POA, the ages of 7, 28, 60 and 90 days were 16%, 21%, 25% and 28%, respectively.

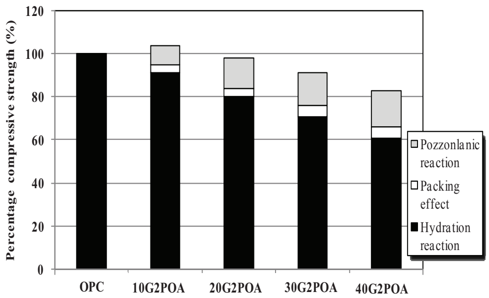
The percentage compressive strength of cement paste due to pozzolanic reaction of the G2POA cement past was higher than that of the G1POA cement paste. Percentage compressive strength due to pozzolanic reaction is increased at all ages. For example, at the age of 90 days, the percentage compressive strengths due to pozzolanic reaction of the 20G2POA and 30G2POA cement paste were 27% and 29%, respectively and compressive strength of G2POA cement paste was higher than that of the OPC cement paste (105-111%). The high fineness of palm oil fuel ash had a greater pozzolanic reaction. Therefore, G2POA can be good pozzolanic materials (Rukzon et al. 2009; Tangchirapat et al. 2009b).

Table 5 : Percentage compressive strength of cement pastes due to pozzolanic reaction

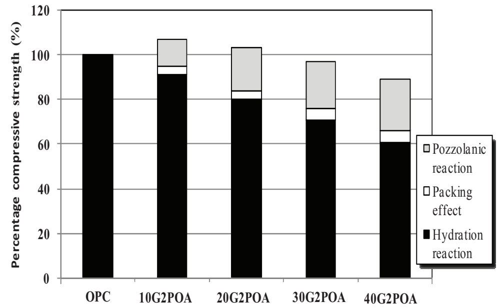
Symbol	Percentage compressive strength due to pozzolanic reaction			
	7 days	28 days	60 days	90 days
10G1POA	4	9	11	12
20G1POA	11	16	20	23
30G1POA	13	18	22	27
40G1POA	16	21	25	28
10G2POA	9	12	15	16
20G2POA	14	19	25	27
30G2POA	15	21	26	29
40G2POA	17	23	27	29

3.6 Percentage hydration reaction, packing effect and pozzolanic reaction

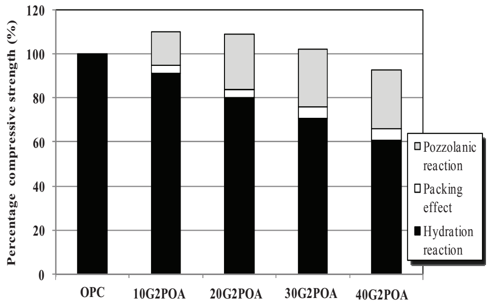
The compressive strength of the cement paste containing palm oil fuel ash size high fineness cement is contributed by hydration reaction, packing effect and pozzolanic reaction as shown in Figure 3. At 7 days, the compressive strength of 10G2POA cement paste was higher than that of OPC cement paste. It was packing effect plus pozzolanic reaction. For example, at the age of 90 days, Percentage hydration reaction, packing effect and pozzolanic reaction of the 30G2POA cement paste were 71%, 5%, and 29%, respectively, while the compressive strength was higher than that of the control cement paste OPC. This indicated that high fineness of palm oil fuel ash had excellent pozzolanic reaction and the small particles could also in the voids of cement paste. Therefore, the G2POA cement paste more homogeneous and denser. This resulted in an increase in the compressive strength (Chindaprasirt et al. 2005; Isaia et al. 2003).



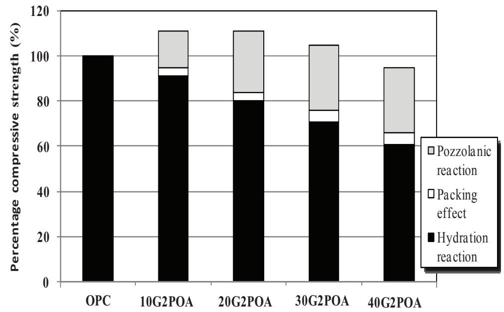
a) 7 days



b) 28 days



c) 60 days

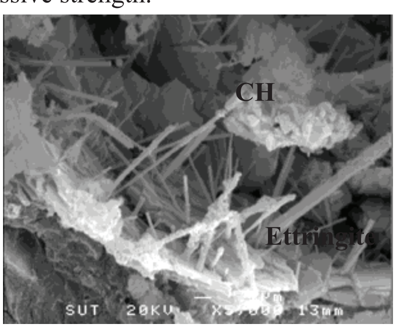


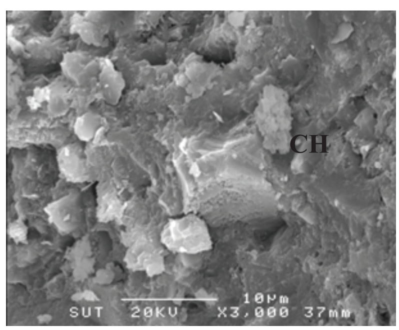
d) 90 days

Figure 3: Percentage compressive strength of G2POA cement paste

3.7 SEM observations

The fractured surface of 20G2POA cement paste is shown in Figure 4. At 7 days, it can be the hydrated product of 20G2POA cement paste, such as C-S-H, $Ca(OH_2)$, ettringite needles. Additionally, the microstructures of 20G2POA cement paste were porous and many void (Chindaprasirt et al. 2007b). Considering 20G2POA cement paste at 28 days had a denser structure. The pore structure changes of 20G2POA cement paste was depicted increased hydration and were pozzolanic, thus resulting in a higher compressive strength.





a) 7 days

b) 28 days

Figure 4: Fractured surface of 20G2POA cement paste

4. Conclusions

Based on the results of this study, the following conclusions can be drawn.

- Palm oil fuel ash with high fineness percentage compressive strength due to pozzolanic reaction is higher than that packing effect.
- The compressive strength of paste due to increased packing effect as 4%, 4%, 5% and 5% when replace Portland cement Type I by sand ground with median particle size smaller than cement at 10, 20, 30 and 40 percent by weight of cementitious materials.
- The compressive strength due to pozzolanic reaction with median particle size smaller than cement replacement cement of 10, 20, 30 and 40 by weight of cementitious materials were 12% ,19% , 21% and 23, respectively, at the age of 28 day.
- Ground palm oil fuel ash high fineness can be used as pozzolan to replace Portland cement Type I at the rate of 30% by weight of binder.

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References

[1] Chindaprasirt P, Homwuttiwong S, and Jaturapitakkul C (2007a). Strength and water permeability of concrete containing palm oil fuel ash and rice husk-bark ash. Construction and Building Materials. 21(7), pp. 1492-1499.

[2] Chindaprasirt P, Homwuttiwong S, and Sirivivatnanon V (2004). Influence of fly ash fineness on strength, drying shrinkage and sulfate resistance of blended cement mortar. Cement and Concrete Research. 34(7), pp. 1087-1092.

[3] Chindaprasirt P, Jaturapitakkul C, and Sinsiri T (2005). Effect of fly ash fineness on compressive strength and pore size of blended cement paste. Cement and Concrete Composites. 27(4), pp. 425-428.

[4] Chindaprasirt P, Jaturapitakkul C, and Sinsiri T (2007b). Effect of fly ash fineness on microstructure of blended cement paste. Construction and Building Materials. 21(7), pp. 1534-1541.

[5] Chindaprasirt P, Rukzon S, and Sirivivatnanon V (2008). Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. Construction and Building Materials. 22(5), pp. 932-938.

[6] Goldman A, and Bentur A (1993). The influence of microfillers on enhancement of concrete strength. Cement and Concrete Research. 23(4), pp. 962-972.

[7] Isaia G. C, Gastaldini A. L. G, and Moraes R (2003). Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement and Concrete Composites. 25(1), pp. 69-76.

[8] Rukzon S, Chindaprasirt P, and Mahachai R (2009). Effect of grinding on chemical and physical properties of rice husk ash. International Journal of Minerals Metallurgy and Materials. 16(2), pp. 242-247.

[9] Sata V, Jaturapitakkul C, and Kiattikomol K (2004). Utilization of palm oil fuel ash in high-strength concrete. Journal of Materials in Civil Engineering 16(6), pp. 623-628.

[10] Tangchirapat W, Jaturapitakkul C, and Chindaprasirt P (2009a). Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete. Construction and Building Materials. 23(7), pp. 2641-2646.

[11] Tangchirapat W, Jaturapitakkul C, and Kiattikomol K (2009b). Compressive strength and expansion of blended cement mortar containing palm oil fuel ash. Journal of Materials in Civil Engineering. 21(8), pp. 426-431.

[12] Tangchirapat W, Saeting T, Jaturapitakkul C, Kiattikomol K, and Siripanichgorn A (2007). Use of waste ash from palm oil industry in concrete. Waste Management. 27(1), pp. 81-88.

[13] Tangpagasit J, Cheerarot R, Jaturapitakkul C, and Kiattikomol K (2005). Packing effect and pozzolanic reaction of fly ash in mortar. Cement and Concrete Research. 35(6), pp. 1145-1151.